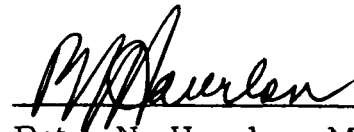


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SUMMARY REPORT ON LUNAR
SURVEY PROBE UTILIZATION
STUDY

APPROVED BY: 

James D. Burke
Advanced Lunar Study Leader



Peter N. Hauran, Manager
Future Project Office

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA

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SUMMARY REPORT ON LUNAR SURVEY PROBE UTILIZATION STUDY

I. OBJECTIVES OF STUDY

In May, 1966, the JPL Advanced Lunar Studies Team initiated the current study of the utility of Lunar Survey Probes (LSP) in a lunar exploration program. Preliminary results were presented in November, 1966 and in January, 1967, and a summary of the scientific conclusions was issued (Ref. 1) in March, 1967. For the purpose of the utilization study, the mission concept was not restricted to any particular type of spacecraft or delivery mode; the scientific objectives were developed as example missions for any small unmanned, stationary payloads resting on the lunar surface.

The JPL team has continued to examine the goals and methods of a post-Apollo lunar exploration program (cf. Refs. 11 and 12); parts of this work have been reported in Refs. 2, 3, 4, and 5 and further results were presented (Refs. 6, 9, and 10) at a NASA summer conference on lunar exploration in August, 1967. The purpose of the present brief report is to summarize the LSP study in the context of the other related study efforts and to indicate the areas where further analysis may be desirable.

II. SCIENTIFIC UTILITY OF UNMANNED LUNAR SURFACE PROBES

In order to describe the utility of LSP in a lunar program including other classes of manned and unmanned missions, it was necessary to make some assumptions about the performance limitations of LSP. The major limitations implied in the LSP study were as follows:

- No mobility after landing
- In-situ analysis only; i. e., no return of lunar material to Earth
- Landing location random within guidance error ellipse having dimensions of the order of kilometers, as is likely for conventional guidance systems
- Instrumentation having complexity and capability in the general class represented by the equipment developed for, but not yet flown on, Surveyor and ALSEP

With these restrictions it is clear that examination of preselected, single small features below the size range visible from Earth is not a suitable role for LSP. General surface reconnaissance with chemical, isotopic, and mineral analysis of locally-selected material near a random landing point is a proper goal. In Ref. 1 the need for general geologic reconnaissance was brought out with reference to the characteristics of the major physiographic units on the Moon that can be seen from Earth. An important exploration objective is to relate the physiographic character of a surface element to its lithology, so as to gain an insight into the genetic nature of, and differences between, physiographic provinces. Examples of instruments that could be used to elucidate these relationships are given in Ref. 5. For instance, a landed payload could include a high-resolution imaging system, a drill and particulate sampler, a sample processor, an X-ray diffractometer, an X-ray spectrometer, a petrographic microscope, and a gas chromatograph for detecting volatile constituents of samples. Such an assembly of instruments would give basic information as to the chemical and mineral character of materials near and at the surface. This information would not in itself be sufficient for a complete understanding of the Moon but it would be an important supplement to the information obtained by (a) orbiters, (b) unmanned mobile surface vehicles, and (c) manned local-area and traverse missions, because it would provide information in areas where each of these three latter mission classes has performance limitations. For example the orbiters would measure surface material properties only indirectly, with moderate area resolution and low or no discrimination among chemical constituents. The unmanned rovers probably cannot carry instrumentation as elaborate as that which could be delivered by a stationary spacecraft of equivalent size, and the manned missions will for some time be limited to operation close to safe, flat landing sites. The scientific need for even rather limited missions into the Moon's remote and rough areas is clear, and a complete program should include both stationary and mobile investigations of these areas to the extent feasible. Because the capability of remote analysis is limited, it would be highly desirable to supplement the in-situ observations by analysis of samples returned to Earth. However, in the program now visualized, the only way to do this is via the manned landings. Therefore, samples from the remote, rough areas would have to be transported to the manned-landing

sites. This is a function for the unmanned mobile units, not for LSP as here defined.*

Apart from geologic reconnaissance, there are a number of other important functions that could be performed by LSP. Reference 4 lists the priority goals in a program dedicated to understanding the properties of the Moon as a member of a planetary system. In addition to the chemical, isotopic, and mineral analyses already mentioned, these priority goals include (a) determination of anomalies in the Moon's gross mass and shape, (b) determination of the presence or absence of a core, (c) measurement of heat flow, and (d) determination of the relationships among the Moon's electromagnetic properties and those of its particle-and-field environment.

Unmanned, stationary probes can contribute importantly to each of these priority objectives. By means of precision radio ranging from and to stations on Earth, as well as possibly to and from lunar orbiters, a network of landed spacecraft could provide accurate data on the figure and motions of the Moon as a non-rigid body. The necessary technique has already been demonstrated by Surveyors and Lunar Orbiters, and indeed has resulted in the discovery of some anomalies in the lunar ephemeris. The remaining uncertainties in the Moon's true shape and deformations are large enough to justify substantial additional effort toward the creation of an accurate selenodetic net. Apart from its basic scientific importance, this work is, of course, also necessary to provide adequate cartographic support for later missions.

The question of a lunar core is recognized as one of basic planetological importance. The main characteristics required of a seismic net for detection and exploration of large-scale density discontinuities in the Moon are (a) widely-separated observing sites, and (b) long-lived instrumentation, the latter because the system is expected to depend on natural seismic or meteoric events, which are expected to be infrequent. The investigations of heat flow and of the electromagnetic and particle environment at the surface are potentially related to the characteristics of the core, as pointed out in Ref. 4. However, regardless of the presence or absence of a core, it will be desirable to make these measurements at several locations; some of these can and should be near manned-landing sites (e. g., ALSEP), and

*In principle, of course, a mobile unit could visit a LSP and receive from it a cargo of processed samples. The relative merits of such a mission have not yet been examined.

others should be far removed. The measurements should be made at several locations during the same time period. Therefore, emplacement of seismic, thermal, and particle-and-field sensors is an important mission for LSP.

The relationship between the measurements just discussed and other measurements (such as mapping from orbit, or isotopic analysis of samples returned to Earth) in a complete exploration program can be seen in Figure 1, which is taken from Ref. 6. Plainly the Lunar Survey Probes have a significant role to play in the initial phases of several major investigations. One of the chief functions of remote-area landings, however, is not explicitly shown in Figure 1. This is simply the validation or scouting function on which later, more elaborate missions are dependent. In any remote lunar region that is found to warrant continued exploration, whether because of intrinsic geological interest, recoverable resources (e. g., water), or suitability as a base, for example for astronomy, it will be highly desirable to conduct both stationary and mobile observations with the specific goal of increasing the yield of later missions. Landing site evaluation is a simple example; other examples are (a) precursor environmental measurements or (b) simplified experiments aimed at defining the goals of a specific, more elaborate future task. For the future manned exploratory missions required in a program directed toward a thorough understanding of the Moon, while some of the experiments are valuable whenever they can be done, others are sequence-critical; i. e., their value is enhanced by proper previous and subsequent investigations. LSP missions could help to provide this enhancement.

III. DESIRABLE CHARACTERISTICS OF DELIVERY, DEPLOYMENT, AND SUPPORT SYSTEMS

A. General

Given the mission goals outlined in the previous section, it is possible to define the main delivery and support criteria for the LSP payloads. In what follows some of these criteria are outlined for several subsystems. However, it should be recognized that any so-called "improvements" required relative to present capabilities should be carefully scrutinized and determined to be scientifically essential before being adopted. The reason is that, in past programs having a high content of engineering novelty, scientific experiments have had to be set aside to make resources available for solving the engineering problems, and then, by the time the

engineering problems were dealt with, no resources remained with which to carry on and exploit the spacecraft in their originally-intended roles. Since the postulated mission of LSP does not include advancement of lunar technology, except as required in support of the immediate mission goals, new concepts should be avoided wherever possible.

B. System Performance

The missions described in Section II typically call for delivery of one hundred to a few hundred pounds of instruments on each flight, to parts of the lunar surface including regions far from the Apollo equatorial landing zone, and ultimately including the Moon's far side. For probes launched directly from Earth, the mechanics of approach trajectories are such as to favor the western longitudes on the Moon. In the Appendix to Ref. 2 methods for extending the Surveyor access area to include most of the Moon, including the poles, were described. For probes ejected from spacecraft orbiting the Moon, as considered in the Apollo-based LSP studies made in 1965 (Ref. 7 and 8), in principle any area within the orbital latitude band can be reached, though of course there are some questions of stay time in orbit and ejection timing.

Since it is assumed that there will be no guided post-landing mobility, and since it is recognized that landing dispersions (for either direct or orbital delivery) will continue to be of the order of kilometers or more, provisions must be made for access to the surface at a location which will be essentially random about the aiming point.

Some of the LSP mission goals imply long lifetime; i. e., survival through the lunar night. For the seismic and particle-and-field measurements, not only survival but also operation during the lunar night would be desired; also, simultaneous operation of multiple LSP and ALSEP payloads would be highly desirable. Simultaneous readout of data might not be desired, because of the demand on Earth-based data acquisition facilities; therefore, on-board recording and playback of some of the data might become a requirement.

C. Telecommunications

The total data content and the commands and data rates for the experiments considered are compatible with a telecommunications system in the Surveyor class.

A desirable improvement, relative to Surveyor, would be the incorporation of a ranging transponder as used in the present Lunar Orbiters. This would increase the quality of the selenodetic and lunar-distortion experiments.

Relay-mode communications via orbiters would be a desirable future addition, not only for the cooperative experiments mentioned in Section II, but also to provide access for LSP to polar, limb, and far-side areas of the Moon.

D. Guidance and Control

As previously mentioned, access to particular, pre-chosen surface features such as single small craters or rocks is not regarded as practical for LSP. The reason is that, even with zero errors in whatever coordinates are used by the guidance system, perfect targeting would not be achieved because, during the time period when LSP utility is expected to be greatest, the lunar ephemeris and the lunar map will still be subject to error. Access to particular features is a task for manned or unmanned mobile vehicles which can be piloted to their targets after landing. The transit and landing guidance requirements of LSP for the seismic mission, for example, are no more demanding than those of Surveyor. In order to improve after-the-fact knowledge of the actual landing location and thus improve the ephemeris and the maps of the Moon, the previously-mentioned radio measurements should be provided, and also possibly optical references to celestial objects, in addition to imaging of the surroundings so that the landing point could be placed on the map.

E. Power

The electrical power demands of the experiments considered are modest, but the night survival requirement raises the question of radioisotope (RTG) power as used for ALSEP. The choice between solar/battery and nuclear power is an item for future study.

F. Structures and Mechanics

Lunar Orbiter pictures of the Moon's rough areas suggest that an LSP designed to deliver instrumentation into them should have more capability than the present Surveyor for (a) safely straddling rocks and (b) remaining stable (or, alternatively, overturning without mission impairment) on steep slopes. In high-latitude or

limb-region rough areas on the Moon, an LSP might land in a depression where it would be out of sight from Earth. Barring relay-mode communications as mentioned above, the LSP should then have, or be able to erect, an antenna high enough above itself to give a reasonable prospect of achieving line-of-sight to Earth. Of course, a high vantage point for the imaging system is also desirable to maximize the viewing area in rough country.

The LSP may have to have a more versatile temperature-control system than that of Surveyor if it is to survive the thermal uncertainties of the rough areas, and also the lunar night.

In general, all of these problems appear to require only straightforward expansion of Ranger and Surveyor experience, but taken together they represent a significant spacecraft development effort. Thus, as mentioned at the beginning of this section, performance extensions should be sought only in those areas where the expected mission yield is large, and if the extensions are attempted the program plan should provide for an adequate exploitation of them once they are achieved.

IV. MAJOR FACTORS TO BE CONSIDERED IN SELECTION OF SYSTEM CONCEPTS

The requirements described in the preceding sections could in principle be met by any one of the following delivery modes:

- (1) Direct, unmanned launch from Earth (Surveyor).
- (2) Manned delivery and emplacement (ALSEP).
- (3) Manned delivery into lunar orbit, unmanned descent to surface (1965 LSP concept, cf. Refs. 7 and 8).

Other modes (such as unmanned delivery from unmanned orbiters) might be considered but have not been examined in the studies to date. Use of only one of the above modes to carry the whole program would be possible but would certainly be inefficient because of the operating limitations, described in Section II above, peculiar to each mode. Therefore, the best program would involve a combination of at least two modes. The major factors to be considered in selecting the best combination of modes are:

- (1) Scientific program yield in proportion to new engineering developments required.

- (2) Utility of any new engineering developments in continued later exploration of Moon and planets.
- (3) Exploitation of payload delivery potential incidental to other missions, such as late post-Apollo manned missions whose primary goal might be the development of lunar surface operations technique.

Based on these considerations, the trend of the studies since 1965 has been such as to favor a program involving Surveyor-type and ALSEP-type missions, rather than a combination involving the descent-from-orbit delivery mode. Mobility on the lunar surface has been recognized as a requirement of the scientific rationale, and this has resulted in the suggestion that new engineering development effort be pointed toward improving surface mobility of the manned and unmanned equipments, rather than toward use of different flight profiles for reaching the lunar surface.

V. COMPARISON OF PROBE CONCEPTS

The 1965 LSP studies envisioned a vehicle ejected from an orbiting Apollo-class manned spacecraft, decelerated by main and vernier propulsion and guidance systems, and then separated from the payload which would fall to the surface from a small height. The payload capsule would be protected by energy-absorbing devices against the final impact. The required techniques for impact protection and post-impact erection and operation were developed in 1960-62 for the Ranger Block II lunar rough-landing capsules, and a related concept was used for the lunar landings of the Soviet spacecraft, Luna 9 and 13, in 1966. The Ranger, LSP, or Luna concept is less sensitive than Surveyor to the roughness or slope of the surface on which it lands, but more constraining on the instrumentation that can be carried and on the data output. Simple imaging, seismic, thermal and radiation instruments have been shown to be practical by the Ranger and Luna tests. More elaborate equipments such as drills, samplers and petrographic microscopes could probably be developed but have not yet been demonstrated. A possibly-useful compromise would be to carry both the simple and the more elaborate equipments on a ruggedized Surveyor with provisions for continued operation of the simpler equipment even after a rough landing or overturn. Some engineering studies of this concept were made during the Surveyor project; it is undoubtedly practical but may not be optimum on a scientific yield/cost basis.

If mobile manned or unmanned surface vehicles become available, they could be used to emplace instruments. However, most of the scientific criteria mentioned in Section II could be satisfied without extensive use of this mode. The mobile vehicles have important functions other than instrument emplacement (cf. Ref. 9).

VI. PROPOSED FUTURE EFFORT

In order to derive a near-optimum program combining manned lunar landings, unmanned probes into remote areas on the Moon, and manned or unmanned surface traverses, it is suggested that efforts be continued at JPL and the NASA Centers concerned with the scientific exploration of the Moon, to translate basic scientific goals into exploration tasks and mission descriptions. The JPL part of this effort is represented by the program-rationale or "matrix" part of the studies being conducted by the Advanced Lunar Studies Team. Based on results of the 1967 NASA Summer Conference on Lunar Exploration, the Team is expected to provide additional comments on surface probe utility.

VII. RESEARCH AND TECHNOLOGY IMPLICATIONS

If the tentative study conclusion mentioned in Section V proves to be correct, namely, that new technology should emphasize post-landing mobility rather than different pre-landing flight profiles, the technology requirements of a scientifically-worthwhile LSP program may not be great. The primary new items required or desired (cf. Section III above) are:

- Extended surface access including polar and far-side areas.
- Rough-area landing and operation capability.
- Capacity for simultaneous data collection at a network of observing sites.
- Radio ranging (now used in Lunar Orbiter but not in Surveyor).
- Geological and geophysical instrumentation.

No single new technique is an absolute necessity. It is well to recall that even a Ranger Block II-class seismic experiment would represent a worthwhile supplement to the ALSEP seismic investigation. However, the potential functions of LSP in an integrated program appear to warrant a modest extension of present technique as represented by Surveyor and ALSEP instrumentation. A significant research and

technology contribution would be to bring this extension of technique into being with a minimum revision of existing systems, so as to counter the tendency of technological resource demands to erode scientific performance, as mentioned earlier.

VIII. CONCLUSIONS AND RECOMMENDATIONS

Since the 1965 and 1966 LSP studies at JPL and elsewhere were not carried to the point of integration of any LSP concept into a complete lunar exploration rationale, no final conclusion was offered as to the suitability and effectiveness of unmanned probes as adjuncts to a manned lunar surface exploration program. It now appears that there is indeed a need for investigation of the Moon's remote and rough areas, and that extension of manned exploration into these areas will occur relatively late in the program. If resources permit, therefore, unmanned experiments in these areas should be included at an earlier stage of the program. Ideally these experiments would be made by some combination of stationary landed probes and unmanned mobile vehicles traveling on the surface. Because the potential of the stationary probes is limited by the essentially random character of their location on the surface, it does appear that if significant new developments are undertaken, these should be directed toward achievement of mobility on the surface rather than toward implementation of new ways for reaching the surface of the Moon. Therefore, it is recommended that the LSP function be carried out by some combination of Surveyor and ALSEP payloads, rather than by a new descent-from-orbit system, and that mission studies be oriented toward determining the specific engineering changes required to realize the performance extensions (e. g. , polar landings, night survival, and data storage) required for operation of a network of stations on the Moon.

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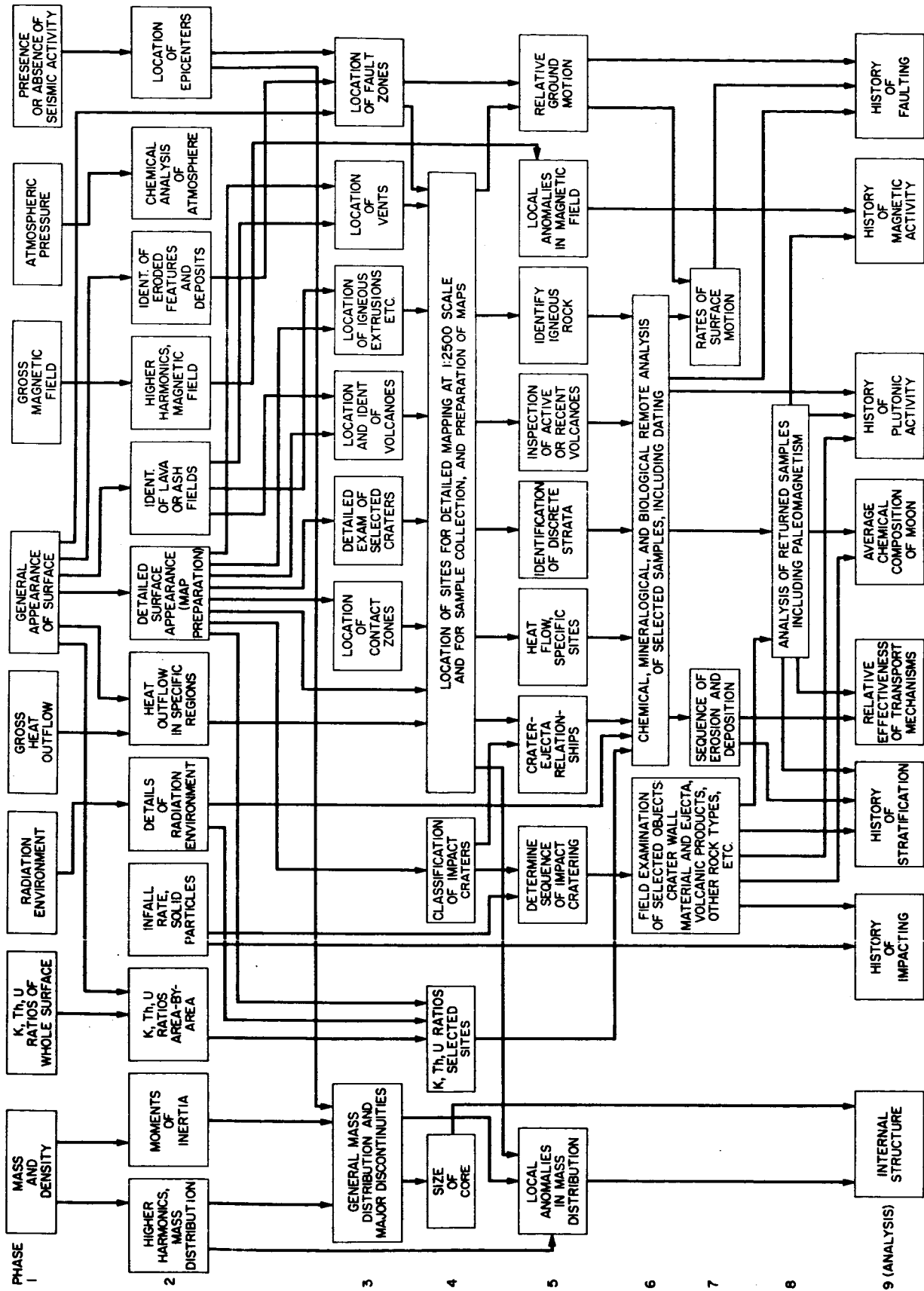


Fig. 1. Major lines of investigation